

Observation of Gamma-Ray Bursts with INTEGRAL

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We expect that at least one Gamma-Ray Burst per month will be detected in the field of view of INTEGRAL instruments and localized with an accuracy of a few arcminutes.

IBIS (the Imager on board INTEGRAL) will be the most sensitive instrument in the soft γ -ray band during the next few years. This will allow INTEGRAL to detect the faintest (and hence the most distant) γ -ray bursts, thus surely contributing to the study of the physics of GRBs and to the comprehension of the early stages of the Universe.

GRBs will be detected and localized in (near) real time with the IBAS (INTEGRAL Burst Alert System) software, and their coordinates will be immediately distributed to the scientific community, allowing for prompt follow-up observations at other wavelengths. The flexibility of the IBAS software, running on ground at the ISDC, will allow us to possibly reveal new classes of bursts, such as ultra-short bursts (\sim ms) or very long ($t > 50$ s) but slowly rising bursts, that could not be detected by previous experiments.

1 Introduction

The origin and nature of Gamma-Ray Bursts (GRBs) have been a puzzling mystery since their discovery in the late 60's¹. This was mainly due to the fact that these short and unpredictable events had been observed exclusively at γ -ray energies and with non-imaging instruments. A great advance came after the launch of CGRO in 1991: BATSE registered a great number (~ 3000) of GRBs isotropically distributed over the entire sky, but with a non-euclidean LogN-LogS slope, suggesting a cosmological origin. The BATSE results contributed to develop a *standard* model for the emission mechanisms of the prompt and the delayed emission: the so called internal² and external³ fireball shock model, involving a relativistically expanding fireball with bulk Lorentz factors of the order of ~ 100 . This model is independent of the nature and details of the GRB progenitors. In fact, despite substantial efforts no certain evidence on the progenitors has been found yet. The cosmological nature of GRBs was confirmed after the discovery of the first (predicted) X-ray afterglow in 1997 (GRB970228) by *BeppoSAX*⁴, which allowed the first successful follow-up at optical wavelengths⁵ and hence its red-shift determination⁶ ($z=0.695$). However, the debate on the progenitors of these sources is still open. While for the long GRBs ($t > 2$ s) the models involving the core collapse of a very massive star seem to be appropriate (e.g. ⁷), very little is known on the short GRBs ($t < 2$ s), for which no counterparts at longer wavelength have been observed yet. In their case, the model of the coalescence between compact objects (NS-NS, NS-BH)⁸ cannot be ruled out.

In this framework a clear requirement of the scientific community is the rapid localization of the prompt emission of GRBs followed by an efficient distribution of the derived coordinates. The INTEGRAL satellite, although not specifically designed as a GRB oriented mission, can greatly contribute to these studies. Its main imaging instrument, IBIS⁹, is very sensitive in the energy range from ~ 20 keV to a few MeV and, coupled with the IBAS software (see § 2) running on ground, it will provide in near real time the positions of the GRBs detected in its large field of view. This can be particularly useful in the case of short GRBs (see § 2.1) to confirm or deny the presence of an afterglow at other wavelengths. In addition, being more sensitive than previous instruments it will be able to detect and localize even faint GRBs at high red-shifts ($z > 10$), which could be associated with Population III stars, allowing us to investigate the early Universe.

2 The INTEGRAL Burst Alert System (IBAS)

The INTEGRAL Burst Alert System (IBAS) is a software system which provides the (near) real time detection and localization of GRBs. The software is run on ground at the INTEGRAL Science Data Centre (ISDC)¹³ and the derived positions are immediately distributed to the scientific community to allow for follow up observations at other wavelengths. Thanks to the properties of the ISGRI detector (IBIS upper layer covering the lowest energy range) the accuracy of the positions is of the order of a few arcminutes or better (see figure 1).

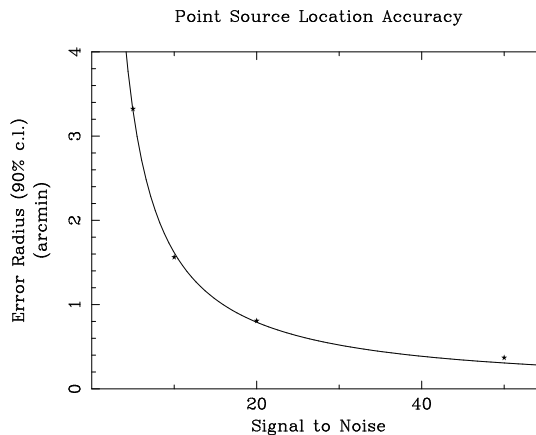


Figure 1: ISGRI point source location accuracy. The line represents a theoretical calculation and the points simulated data (Mereghetti et al. 2001).

Thanks to the fact that the software is run on ground, there is great flexibility in the choice of parameters and in the optimization of the triggering algorithms. For ISGRI two different methods have been implemented to search for GRBs: one, based only on imaging, looks for the appearance of new sources by comparing the instantaneous image of the sky with those obtained previously. The other one looks for statistically significant excesses in the overall count rate on various time scales and uses the imaging only as a confirmation to distinguish real sources from background variations or other instrumental effects. The latter algorithm is particularly efficient for short burst, while the former can successfully be used in the case of slowly rising bursts (see § 2.1). Multiple instances of both algorithms can run simultaneously with different parameters, such as energy channels interval, integration time scales, etc. The IBAS software has also the capability to automatically reconfigure the INTEGRAL Optical Monitoring Camera (OMC), by sending an appropriate telecommand, when a GRB is located within its field of view ($5^\circ \times 5^\circ$, but only a limited number of predefined small windows are observed).

2.1 IBAS Performances for very short and long GRBs

We expect to detect and localize ~ 1 -2 bursts per month in the IBIS field of view¹⁰ (29° Full Width Zero Response). This estimate is based on the extrapolation of the log N-log P distribution obtained with the BATSE on-flight triggers¹¹. IBIS will be the most sensitive instrument in the soft γ -ray range during the next years (note that Swift¹², which is based on a similar detector technology, has a greater effective area (factor ~ 2), but a higher background due to the cosmic diffuse radiation since it has a larger field of view (factor ~ 9)). As a result of the better sensitivity, we expect to extend the lower end of the BATSE log N-log P distribution (detecting the faintest and hence the most distant burst ever), to possibly discover a population of ultra-short bursts (\sim ms) and to detect very long GRBs ($t \gtrsim$ minutes) even if they have a slowly rising time profile.

We have performed several simulations to show how the parameter space of detected GRBs can be extended. This is shown in Figure 2, where the IBAS sensitivity, as estimated from theoretical calculations, and the results of the simulations are plotted over the Peak Flux vs. T90 duration of all the GRBs contained in the BATSE 4B catalog¹¹. Figure 3 shows the reconstructed 15-300

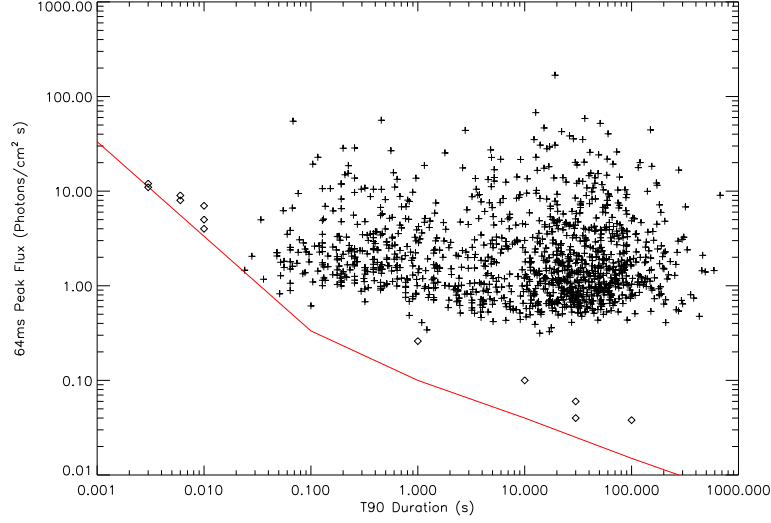


Figure 2: Crosses: BATSE on-flight triggers. Diamonds: IBAS “successful” simulations (i.e. the GRB was detected and localized correctly)

keV image of one of the very short bursts. The light curve of a very long and slowly rising GRB,

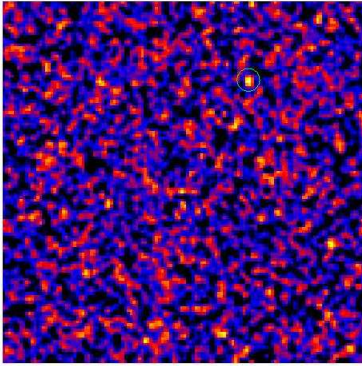


Figure 3: ISGRI image of a 10 ms burst generated with IBAS

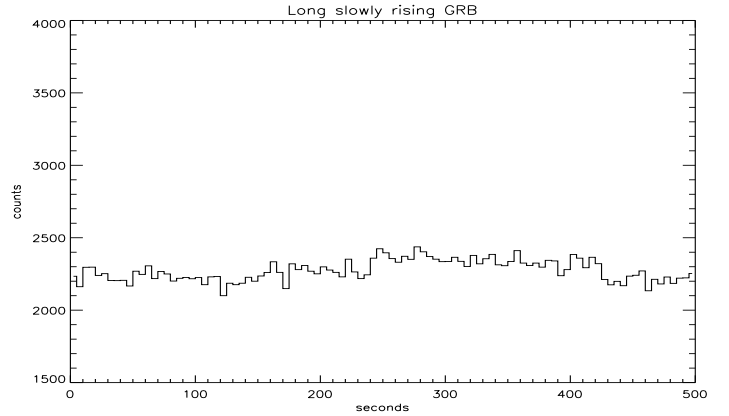


Figure 4: IBAS light curve (15-300 keV, time bin=5 s) of a long but slowly rising burst. The burst begins at $t=200$ s and lasts for about 150 s.

that has been successfully detected in one of our simulations, is shown in figure 4. Such kind of GRBs, if they exist, are difficult or impossible to detect with non-imaging instruments often operating in conditions of variable background, while the IBAS imaging algorithm, when used with the appropriate parameters, can detect them.

2.2 X-ray Flashes

A potentially new class of transients, the X-ray Flashes¹⁴, has been observed with the *BeppoSAX* Wide Field Cameras (2-25 keV). These sources have spectral (non-thermal spectra) and temporal

characteristics similar to the GRBs, but they are not detected in the *BeppoSAX* GRB Monitor (40-700 keV). They could be a population of super-soft GRBs or a completely different class of sources. Some of these X-ray Flashes (about 10) have been detected in an off-line scan of BATSE data¹⁵, but they were too faint to activate the on-board trigger. Since ISGRI has a lower energy threshold than BATSE, it will be particularly sensitive to these events characterized by a softer spectrum.

We have performed some simulations using the parameters of the X-ray Flashes detected by both the WFCs and BATSE off-line, extrapolating the WFCs spectra (single power laws) to the ISGRI energy range. For comparison we have simulated also a *classical* GRB ($\alpha=1$, $\beta=2.25$, $E_p=250$ keV)¹⁶ with the same peak flux. The light curves (time bin=0.5 s) in various energy bands of one of the X-ray Flashes ($\alpha=2.2$) and of the GRB are shown in figure 5. The spectral difference between the two events is clearly visible by comparing their light curves at different energies.

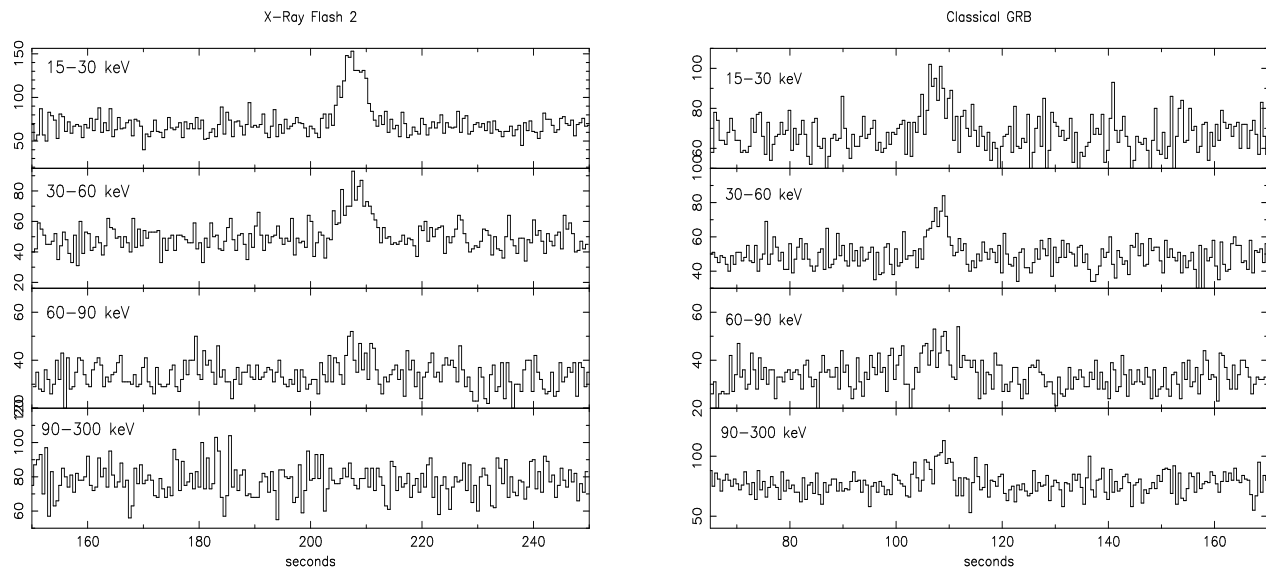


Figure 5: Simulated light curves of an X-Ray Flash and a *classical* GRB in various energy bands.

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